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Investigations on the Control of the European Corn Borer

Raimon L. Beard and Neely Turner

Connecticut
Agricultural Experiment Station
New Haven

FOREWORD

Two phases of the problem of controlling the European corn borer are discussed in this bulletin. The first concerns biological aspects of the problem, reporting research conducted in 1940 and 1941. The second deals with actual tests using insecticides, covering the period 1936-41. Obviously, little application of the facts discovered in the biological investigations has been made in the insecticide investigations reported in this publication.

The insecticidal phases have been carried out in cooperation with the Division of Cereal and Forage Insects, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture. Earlier cooperative work involving both organizations working on single projects was reported in Bulletin **395.** Specific projects have been carried out by each of the cooperating agencies since that time. The work reported here was done by the Connecticut Agricultural Experiment Station.

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PART I. BIOLOGICAL ASPECTS

Raimon L. Beard

The effective control of any insect must necessarily be based upon a knowledge of the life history and habits of the insect in question. When the European corn borer first arrived in this country, the economic injury caused to host plants in Europe and Asia was well known, but fundamental facts regarding the bionomics of this insect were very meager. Although the corn borer was probably introduced into North America on broomcorn in about 1910, its establishment was not recognized until 1917, when Vinal reported its presence in the vicinity of Boston and immediately began an investigation on the biology of the borer. His first paper (20) gave a brief account of its life history and habits. This was followed by a more detailed treatment by Vinal and Caffrey (21). Caffrey and Worthley (6) summarized comprehensively the work done in the nine years following the discovery of the corn borer in this country, during which time the insect spread to several of the New England states, eastern New York and a rather extensive area around Lake Erie. This account is of importance in the present connection in that the life history of the borer in the New England area is given, and general habits of the borer are discussed. When the borer became well established in Ohio, the Ohio Agricultural Experiment Station undertook an extensive investigation of the fundamental biological aspects of the infestation, particularly those concerned with the interrelationships of the borer and its hosts and its reaction to its environment. The results of these investigations appeared in a bulletin by Huber, Neiswander and Salter (11) and in shorter reports since that time by these men, their co-workers, and others. These workers were concerned with the strain of corn borer which has but a single generation each year in contrast to the bivoltine strain which occurs in Connecticut.

For a number of years the principal means of control centered around cultural methods and clean farming practices and a considerable amount of work has been done in an effort to bring about control through the biological agents of predators, parasites and diseases. At the present time in Connecticut, emphasis is being placed upon insecticides as a means of reducing borer damage to sweet corn.

The fundamental observations upon which insecticide treatments are based go back to those mentioned above. The life history for

the New England strain, as outlined by Vinal and Caffrey (21), involves two generations a year. The moths of the first generation fly and oviposit from the latter part of May until the last of June or early July. The oviposition period for the second generation extends from the latter part of July until early September. For Connecticut this means that early corn may be severely damaged by the borer, but corn maturing in August is relatively free from injury. Late corn, maturing in September, is heavily infested by the second generation of borers. Effective treatment of this late corn may be minimized in value by the injury caused by the corn ear worm and the armyworm, which are not controlled by the corn borer treatment. Turner (19), however, has demonstrated that treatment of early sweet corn may be highly profitable.

The insecticide used to best advantage in Connecticut is the dual-fixed nicotine dust which has been developed by Batchelder (2). The standard method of treatment has been to apply the dust four times at five-day intervals, beginning when corn borer hatching is first observed in the field. The first two treatments are made to the growing whorls of the main stalks, whereas the subsequent applications are directed to the leaf axils, particularly those in which the ear shoots are developing. The placement of the toxic material is based upon certain habits of the borer which tend to expose the larvae to the possible action of the dust. The original observations of Vinal (20) indicated that many of the larvae initially feed on the developing tassel buds, later migrating downward to enter the stalk. It was further pointed out that, in older corn, larvae enter the ear directly. Feeding habits of the borer were discussed by Batchelder and Questel (1), but Caffrey and Worthley (6) described more fully the activities as follows:

In plants in which the tassel has not yet developed,

> "....the newly hatched larvae feed at first upon the upper and lower surfaces of the tender leaf blades, thus excavating small irregular-shaped areas in the epidermis. Some of the small larvae may also perforate the leaf blades surrounding the tassel, or work their way between the leaf blades and feed upon the developing tassel within. Once inside the tassel cavity, they feed upon and within the tassel buds. As the tassel expands and the larvae become larger, they enter the tassel stem or its branches and feed within. Instead of feeding upon and within the tender leaf blades and tassel, some of the newly hatched larvae habitually migrate to points lower down on the same or near-by plants, where they may enter the plant at practically any point, although their favorite place of entrance is between the leaf sheath and the stalk. Later in the development of the plant many of the larvae also enter between the stalk and the base of the ear, or they may enter the ear directly.
>
> "When the eggs are deposited upon corn plants which have reached the tassel stage, the newly hatched larvae usually do not attack the tassel, nor do they feed to any extent upon the surface of the leaf blades; under these circumstances they enter the stalk directly, or the thick midrib of the more tender leaf blades. If the plant has developed an ear, the newly hatched larvae frequently feed upon the tender tips of the husks and upon the silk, or work their way down between the silks into the ear and feed upon the grain and cob."

Essentially the same observations, in perhaps greater detail, were made by Huber, Neiswander and Salter (11) on the single generation strain of borer in Ohio.

On the basis of present control methods, 85 percent reduction of the borer is about as high a control as can be expected, even under the best of conditions. This is not entirely satisfactory, as anything short of nearly 100 percent necessitates the sorting of ears at the time of picking if the corn is to be marketed as borer-free. And at present, most farmers object to the additional labor involved in the sorting, even if the corn labeled as borer-free does bring a premium price.

With a view toward improving the effectiveness of insecticidal treatment, observations begun in 1940 were directed toward the feeding habits of the borer in Connecticut, the source of the ear infestation, the identification of more precise relationships between the development of the borer and the growth of corn, and any pertinent data which would aid in the timing and placement of insecticide applications.[1]

Relation of Corn Borer Population to Plant Growth

References to literature indicate a number of factors associated with the development of the host plant which may affect the population of borers.

Working with the one-generation strain of corn borer, Caffrey and Huber (5), Patch (15, 16), Marston and Dibble (13), Kelsheimer and Polivka (12), Ficht (7), Hervey and Hartzell (9), Polivka and Huber (17) and Hervey (8) reported that early planted corn was more heavily infested than late-planted corn. Schlosberg and Mathes (18) also noted this, but observed that a second generation might modify the value of late planting in reducing injury.

This diminished infestation in late corn appears to be due, in part at least, to a partial escape from oviposition. Patch (15) stated that height of corn, or a factor such as maturity correlated with height, is the chief factor in the selection of corn by the moth for oviposition. Ficht (7) reported that plants are not oviposited upon until they reach an "attractive height," which, he said, is about 15 inches, but varies with the variety. Polivka and Huber (17) reported that the height of corn at the period of moth flight is a dominant factor influencing the oviposition of the corn borer. Kelsheimer and Neiswander (11) found that the number of eggs deposited varies directly with plant height.

In addition to the partial escape from oviposition by the later-planted corn, there is evidence to indicate that the late corn is less able to support the borers which do emerge from eggs deposited thereon than is the early corn. Neiswander, Polivka and Huber (11) concluded that, regardless of variety or planting date, the borer

[1] The writer was assisted in making these observations by Mr. Neely Turner and Mr. George Allen.

population per stalk was correlated directly with the earliness of silking date. Ficht (7) observed a close correlation between the survival of borers and the silking date of corn. Of eight varieties of corn, the earlier varieties supported more larvae. Kelsheimer and Polivka (12) noted that on Smoky Dent corn, planted May 15 and June 8, about three times as many borers survived on the early planting as on the late planting. Polivka and Huber (17) placed 5,000 eggs on 100 stalks of corn planted May 15, and another 5,000 on 100 stalks of corn planted June 8. The number of larvae reaching maturity on the earlier corn was four times as great as on the late-planted corn.

Contrary to these reports, Patch (15) concluded that the percent survival of corn borers was not dependent on the maturity of the corn, or on its planting date, or date of tasseling or silking. Later, however, Patch (16) published data which indicated a greater survival of borers with earlier corn planting dates. Marston and Dibble (13) believed that the borers are able to survive equally as well on the late-planted corn as on the early planted corn after the eggs have once been laid.

From these various reports, which have been drawn almost entirely from work done on the univoltine strain of corn borer, and although there is some disagreement, it seems certain that conditions of a fundamental nature in the development of corn must affect directly or indirectly the borer population. Just what these conditions are has not been determined. Since the stage of development of a corn plant on a given date might vary, due to the time of planting, to varietal growth habits or to the environmental factors contributing to its growth, some standardization of growth stages with which borer populations may be associated is necessary. The silking date has been a stage of development useful to many of the workers mentioned above, but this is quite inadequate.

Characteristics of Corn Development

Batchelder (unpublished manuscript) has made the first contribution toward the standardization of growth data by classifying the characteristics of corn development into 11 descriptive categories. These stages are sufficiently well-defined as to be readily distinguishable, and hold well for the sweet corn hybrids Marcross and Carmelcross, which were used by the present writer. These stages, together with the most important diagnostic characteristics, are as follows:

Stage	Symbol	Characteristics
Pre-whorl	P-W	From one to five leaf blades in addition to the primary leaf blades.
Early whorl	W-1	Six or seven leaf blades, exclusive of the primaries, in a distinct whorl.
Mid-whorl	W-2	Eight to nine leaves composing the whorl. Rudimentary tassel completely enclosed by whorl.

Stage	Symbol	Characteristics
Late whorl	W-3	Tassel just becomes visible in the bottom of the whorl cup. One or two small ear shoots may be visible.
Early green tassel	T-1	Tip of the tassel shows above edge of the whorl. Two to four ear shoots are present.
Mid-green tassel	T-2	Tassel shows as a clump of adhering branches.
Late green tassel	T-3	Entire tassel unfurled with branches spread away from tassel stem; pollen sacs swelling with a few anthers showing. Three to five ear shoots present.
Early silk	S-1	Top ear shoot shows fresh silk, yellowish green in color. Anthers dehiscing.
Mid-silk	S-2	Silk of top ear fully extended with deeper color and some wilting. True ears are distinct from rudimentaries. Pollen shedding is at maximum.
Late silk	S-3	Silk dried at tips. Anthers are usually gone; pollen sacs are empty.
Roasting ear	R-E	Corn is ripe for harvest.

The present writer employed still another stage not included in the above. This is called the Seedling stage (Sg), which is characterized by the presence of a single primary leaf blade.

Corn Borer Oviposition and Its Relation to Plant Development

Although there is little doubt that the height of corn largely determines the extent of oviposition, and that it is impracticable to chemically treat corn plants smaller than 15 inches in height, it was desirable to identify the oviposition tendencies more closely with stages of development of corn. This would be of particular interest in view of the conclusion of Neiswander and Huber (14) that the average height of corn in a plot, rather than the height of individual plants within a plot, determined the distribution of eggs.

For the second generation of corn borer in 1941, oviposition records were taken on various stages of corn throughout the oviposition period. To provide a series of growth stages for this period, corn was planted at four-day intervals, beginning July 1, for seven plantings. In addition, one planting made in another field on July 1 was utilized because it grew at a more rapid rate than did the others, and hence provided the later growth stages. The natural oviposition was noted on 25 plants in each of the eight plantings. The data obtained were not as complete as desired, since all stages of plants were not present throughout the season. Part of this was due to the fact that the moth flight began sooner than had been anticipated, so that the later growth stages were not available to the adult borers early in the season. Also a continuous series was not available because of the difference in the growth rate between the corn in the separate fields.[1] The data obtained and shown in Table 1 indicate the number of eggs deposited on the 200 plants throughout the season in respect to the stage of plant growth. The seasonal oviposition trend exhibits a peak during the first two weeks of August, with a small secondary peak occurring from August 22 to 25. The data in terms of corn

[1] The field in which the seven plantings were made was opened to cultivation for the first time in several years and had a high aluminum content. Although lime had been applied, it had been done so late that the corn was delayed in its growth.

Table 1. Seasonal Oviposition of Second-Generation Corn Borer

	July		August								September		Total
	24	28	1	5	9	13	17	21	25	29	2	5	
Seedling													
Pre-whorl													
Early whorl				12	25	44							81
Mid-whorl			170	114	292	142	38						756
Late whorl	45				24	447	22		74				612
Early tassel		64	53			269	41	41	22				490
Mid-tassel			43	243			58	36				19	399
Late tassel				131	162				86	45			424
Early silk				46	56	16				14	16		148
Mid-silk						72	16		92	27			207
Late silk									22				22
Total	45	64	266	546	559	990	175	77	296	86	16	19	3,139

growth stages are only suggestive of certain conclusions, as it is not possible to know what the distribution of eggs would have been on a given date if all growth stages had been available for oviposition. It is apparent, however, that no eggs were laid on plants in the seedling or pre-whorl stages. Relatively few eggs were placed on plants in the early whorl stage, and these went on only when oviposition was at its height. Although not clearly defined, there seems to be a tendency for a fewer number of eggs to be placed on plants in the silking stages than on plants in the latter whorl and tassel stages. There also seems to be a tendency for the preferred stages to be older as the season progresses. Thus, after August 17 no eggs were deposited on plants smaller than the late whorl stage, even though earlier stages were present and available to attack.

It commonly happens during the oviposition period of the first generation, and frequently during the oviposition period of the second generation, that all stages of plant growth are not available for oviposition. Probably the situation in which all stages of plant growth are available—as was desired in the experiment just mentioned—is rarely achieved in practice. When one stage or only a few growth stages of corn are available for corn borer oviposition, there are several possibilities which may depend upon what stage or stages might be available. If all plants are smaller than the "attractive height", the moths could deposit all or part of their eggs on the small corn simply because taller host plants were not available; the moths could withhold their eggs, thereby reducing the total population of borers; or the moths could seek host plants other than corn, and there deposit eggs. Of these possibilities, the last appears the most likely. During the flight of the second-generation borer in 1941 most of the corn in the observation plots at Mount Carmel was smaller than the attractive height. The few small plots of corn which were beyond the mid-whorl stage received eggs, but the rest of the corn did not. Examination of smartweed (Polygonum), another favored host plant, growing near the corn, disclosed that a considerable number of corn borer eggs had been deposited on this plant.

When the corn is at an attractive height at the onset of moth flight, and plant growth synchronizes with corn borer development, a high total population of the borer results. This was pointed out by Houser and Huber (10). This situation commonly occurs on the earliest sweet corn grown in Connecticut. This, together with the fact that the first corn on the market brings a premium price, suggests why it may be highly profitable to chemically treat the corn for borer control. As the season progresses, however, more and more corn escapes serious injury, until that which matures in August is relatively free from borer injury.

Obviously there is a period of time during the oviposition period of the first-generation borer beyond which it is unprofitable to dust the corn. A definition of this time, based upon the oviposition habits and survival of progeny on plants of various growth stages, is desirable. From an economic point of view it is important to know when not to dust just as it is essential to know when dusting is advisable.

Relation of Plant Development to Corn Borer Survival

Experiments were designed to test the establishment and survival of borers of the second generation relative to plant growth stages. Known numbers of eggs were affixed to the leaf surfaces and stalk (if present) of plants in the seedling, pre-whorl, early whorl, mid-whorl, late whorl, early green tassel, mid-green tassel and late green tassel stages. Only eggs actually in the process of hatching, or black-spotted eggs due to hatch within a few hours, were used. This insured against the diminishing of larval survival by egg mortality. Naturally deposited eggs were removed from these plants, which were examined at frequent intervals for this purpose. Thirty plants of each growth stage were infested, each plant, with the exception of the smaller ones, receiving approximately 75 eggs. The small leaf surface of the seedling and pre-whorl stages did not permit the attachment of as many eggs. The establishment and survival of the larvae were determined by dissecting 10 plants from each group at intervals of 10, 20 and 30 days after the infestation was made. The larvae were recorded as to age and position in the plant.

The data showing the number of borers in each instar in the plant at time of the dissections are shown in Table 2 and, graphically, in Figure 1.

It will be seen that, in the plants dissected 10 days after infestation, borers of the first three instars were found, the greatest number being in the second instar. The two larvae in the fourth and fifth instars, respectively, were obviously migrant individuals from other plants. It is also apparent that plants smaller than the late whorl stage at the time of infestation did not support an appreciable number of borers.

The plants dissected 20 days after infestation should demonstrate a distribution of borers comparable to that in the plants dissected

TABLE 2. SURVIVAL OF BORERS RELATIVE TO STAGE OF PLANT GROWTH AT TIME OF INFESTATION

Number of Borers in Plants 10 Days After Infestation								
Growth stage when eggs were attached	Sg	P-w	W-1	W-2	W-3	T-1	T-2	T-3
No. eggs attached	399	617	735	738	823	774	767	744
Borers I instar		1	1	12	1	8	8	1
II	1		2	6	90	103	95	111
III				1	18	10	3	29
IV							1	
V						1		
Total Borers	1	1	3	19	109	122	107	141
Number of Borers in Plants 20 Days After Infestation								
Growth stage when eggs were attached	Sg	P-w	W-1	W-2	W-3	T-1	T-2	T-3
No. eggs attached	480	690	750	763	796	819	813	742
Borers I instar							3	
II	2	2	1	1	6	4	6	1
III			5	16	13	21	34	39
IV				15	39	52	59	71
V					1	3		8
Total Borers	2	2	6	32	59	80	102	119
Number of Borers in Plants 30 Days After Infestation								
Growth stage when eggs were attached	Sg	P-w	W-1	W-2	W-3	T-1	T-2	T-3
No. eggs attached	404	771	760	722	774	723	800	537[1]
Borers I instar					1	1		
II	1	1	5	3	3	5		
III	1	1		3	9	14	2	3
IV		1	16	44	26	34	28	16
V			6	45	98	119	164	93
Total Borers	2	3	27	95	137	173	194	112

[1] Only eight plants.

earlier, except that the borers should be in an older stage. It is true that more borers were in the fourth instar than in others, but there is not the sharp increase in borer population in the late whorl stage over the mid-whorl stage that was evident before. Instead, a more gradual, but marked, gradient of survival is apparent, increasing with the advancing growth stage. In this series, the survival of borers in seedling, pre-whorl and early whorl plants is negligible, and the survival in the mid-whorl plants is of questionable significance.

Again, the plants dissected 30 days after infestation should show a similar distribution of borers except as to age. It is certain that the first, second, and probably the third, instar borers found in these plants did not develop from the eggs placed on the plants, but were migrants or developed from eggs which were accidentally overlooked when the natural oviposition was removed. Here again the plants infested when in the seedling, pre-whorl and early whorl stages are unable to support a significant borer population.

It seems apparent that all borers do not develop at a uniform rate. Although critical data are not available, it is suggested from observation that, in the early stages of plant growth, the borers resi-

dent in the tassel develop at a more rapid rate than those elsewhere in the plant. This implies a nutritional effect—which is not borne out by the laboratory experiments of Bottger (4), who found that the tassel, segregated from the plant and hence subject to drying, was not as conducive to growth as were other parts of the corn plant.

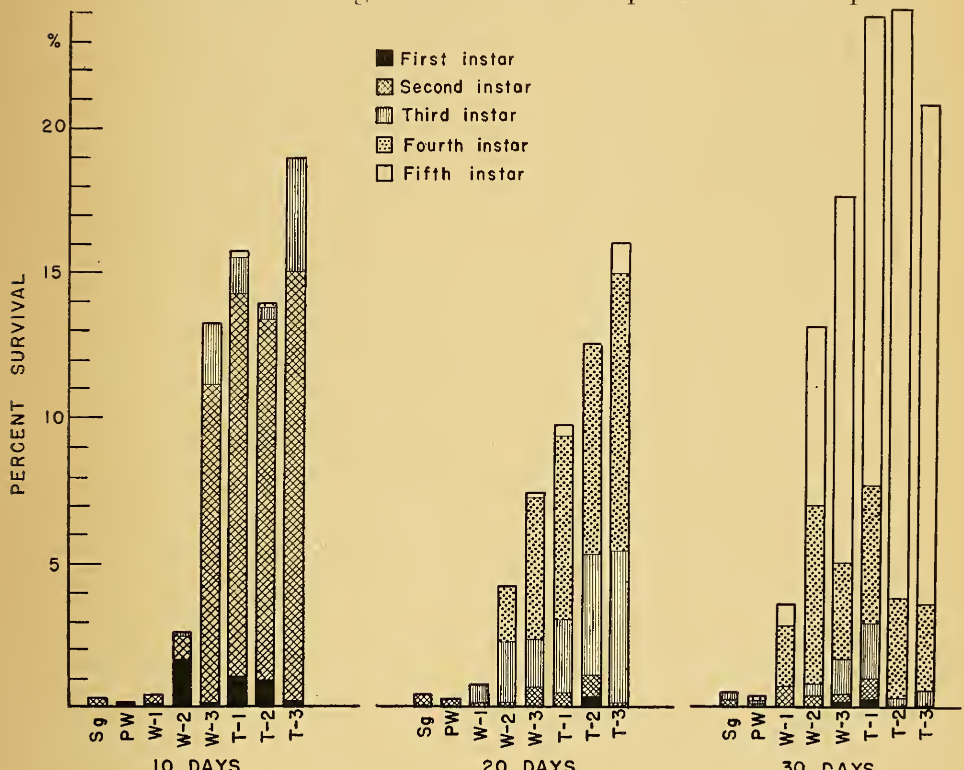

FIGURE 1. Survival of borers relative to stage of plant growth at time of infestation. Survival data based on dissections 10, 20 and 30 days after infestation.

The reason for the lack of establishment and survival in the young corn plant is not definitely known, but it is obvious that a change occurs in the corn plant in the mid or late-whorl stages which might be reflected in nutritional or other factors favoring survival of the larvae. It is just at these stages that the tassel is developing rapidly. In the mid-whorl the tassel is rudimentary and is entirely enclosed by the whorl leaves, but by the late-whorl stage the tassel tip is visible at the bottom of the whorl cup. The tassel as a location favorable to the borer will be further discussed below.

Location of Corn Borers in the Host Plant

The general feeding habits of the corn borer in Connecticut are as described by Caffrey and Worthley (6) mentioned before. Observations previously reported (3) clearly indicate that in the first

generation, when the growth of the corn and the development of the larvae are coincident, most of the early hatching borers become established in the tassel, later leaving that structure to enter the stalk or other parts of the plant. Later, when the ear shoots are developing, the borers infest these structures directly. In the second generation, the corn used in the observations (1940) possessed ear shoots at the time of insect attack, and these structures attracted the borer to a proportionately greater extent than did other regions of the plants. The ears or ear shoots, then, become primarily infested if these structures are present at the time of insect attack, and secondarily infested when the migrants from the primarily infested tassel enter the ear shoots. Estimates on the infestation of the first-generation borer in 1940 indicated that the ears were primarily attractive when 70 percent of the borer population was being established, and secondarily attractive when only 30 percent was being established. On the same basis and on the first corn grown at Mount Carmel in 1941, the ears were primarily attractive when approximately 60 percent of the borer population was being established, and secondarily attractive when about 40 percent of the population was being established.

The use of the word "attractive" does not imply that the plant structure possesses some inherent characteristic which directs a defin-

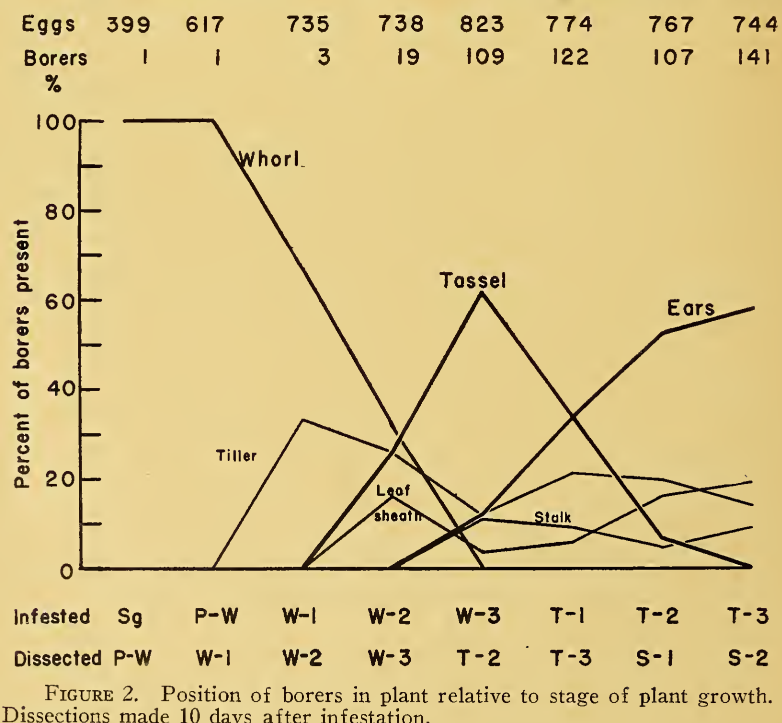

FIGURE 2. Position of borers in plant relative to stage of plant growth. Dissections made 10 days after infestation.

ite movement of the larvae to it. While it is not denied that certain tropisms may be satisfied by conditions in the structure, it is believed that the young larvae wander over the entire plant seeking points of establishment. If a suitable spot is found, the larvae remain; otherwise they move elsewhere or perish. The tassel and the developing ears are the two structures which seem to offer the best conditions for survival—whatever these conditions may be—and in this sense are said to be "attractive."

Further data obtained in 1941 bear out earlier observations on the plant structures frequented by the borer. The plants of different growth stages on which were made the observations on survival, discussed above, also yielded data on the location of borers. These data are shown in Figures 2, 3 and 4.

In each case the percents of the total number of borers present in the whorl, tassel, ears, tiller, leaf sheath and stalk are plotted. Above each chart is given the number of eggs applied to 10 plants in each of the growth stages indicated below the chart. The number of borers found in these plants at the time of dissection is given. The stages of the plants at the time of dissection, which was made 10 (Figure 2), 20 (Figure 3) and 30 (Figure 4) days after the time of infestation, are also shown. An example may serve to illustrate

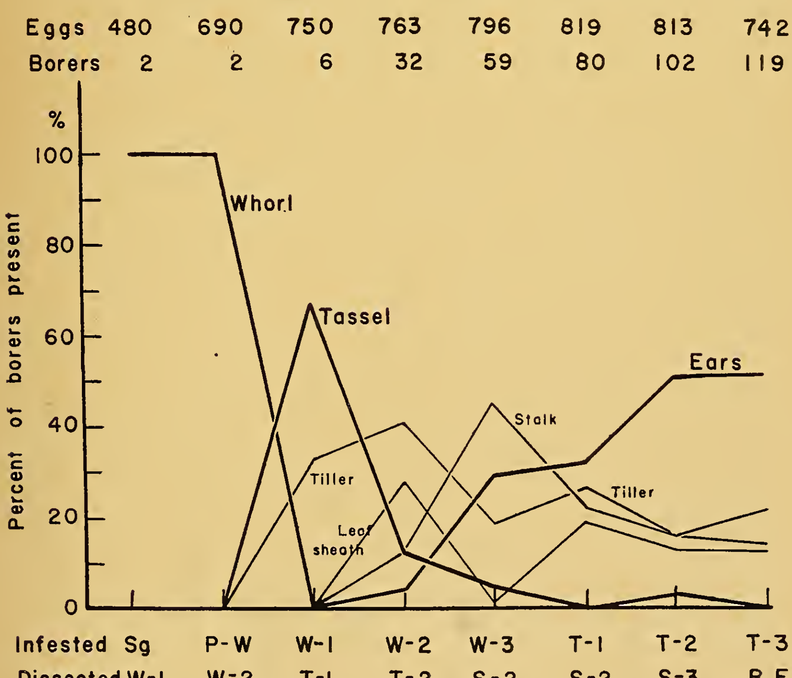

FIGURE 3. Position of borers in plant relative to stage of plant growth. Dissections made 20 days after infestation.

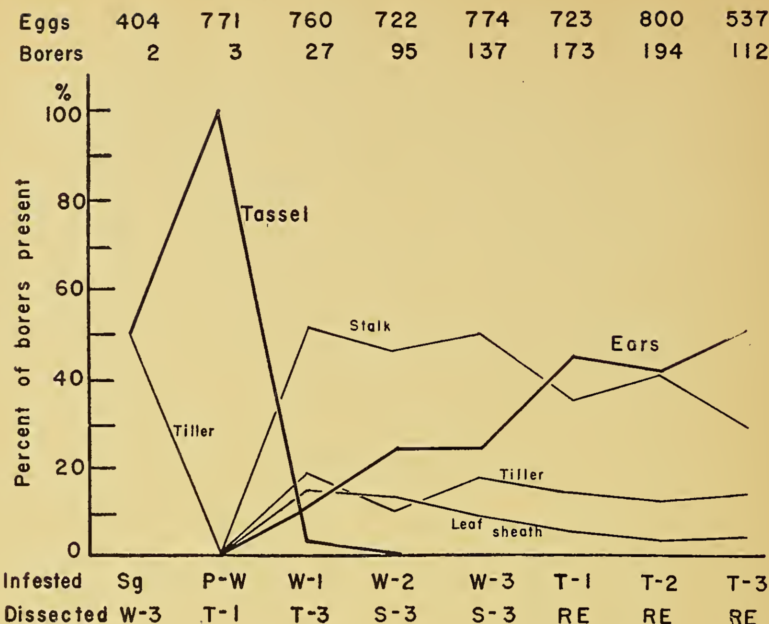

FIGURE 4. Position of borers in plant relative to stage of plant growth. Dissections made 30 days after infestation.

the interpretation of these data. In Figure 2, for instance, it may be seen that 823 eggs were placed on 10 plants in the late whorl stage. Ten days later these plants were in the mid-green tassel stage, and upon dissection were found to harbor 109 borers. Of these 109 borers, 61 percent were in the tassel, 12 percent were in the developing ears, 12 percent were in the tillers, 11 percent were in the stalk and 4 percent were in the leaf sheaths.

In the very early stages the whorl is the principal shelter for the borers. In itself, the whorl infestation is unimportant for two reasons. First, the number of borers thus infesting the whorl is almost negligible and, secondly, the whorl is a transitory arrangement of the leaves, and any borers resident in the whorl must eventually seek other structures. The tassel is the most readily available structure, and in general the tassel absorbs the whorl population (compare Figures 2 and 3).

It will readily be seen that the tassel is very attractive to the larvae. As mentioned before, the tassel first appears as a rudiment in the mid-whorl state, and it may harbor corn borers even at this stage. But the greatest tassel population is found when the plant is in either the early or mid-green tassel stage. In plants older than the early silking stage, however, few if any borers may be present in the tassel.

The ears show a progressively increasing attractiveness from the beginning of their development in the late whorl or early green tassel stage. This increase is coincident with the decrease in attractiveness of the tassel. Although this fact could suggest that the borers which had been harbored by the tassel migrated to the ears, it appears more likely that the primary infestation (i. e., that caused by newly emerged larvae rather than migrants) which went to the tassels when the plants were young, goes to the developing ears in the later plant stages.

The infestations in the tillers and the leaf sheaths of the main plant show no marked changes which can be correlated with plant growth.

The population in the stalk shows no definite trend correlated with the different plant stages at time of infestation, although in the series dissected 20 days after infestation a marked peak occurs in the plants infested in the late whorl stage. On the other hand, if these data are considered in terms of the three dissection dates, the level of the population in the stalk increases in the later dissection groups. This may be more obvious if the data are plotted as in Figure 5.

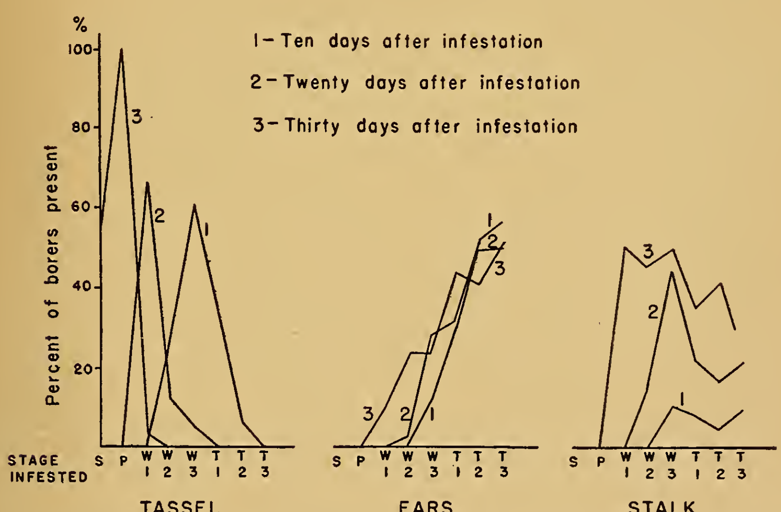

FIGURE 5. Population trends in the tassel, ear, and stalk of plants in series of growth stages dissected 10, 20 and 30 days after infestation.

Although in this figure the data are plotted relative to the stage of the plant at the time infestation was made, it must be remembered that, at the time the dissections were made, the plants were in later stages. This accounts for the shift of the curve showing tassel infestation to the left with each dissection. The high peak in the tassel population in the plants dissected 30 days after infestation is

not important since only three larvae were involved. What is important is that the tassel population drops off to practically nothing after the plants reach the early silking stage, as has been pointed out before. And also as has been pointed out, this means that the borers which had been in the tassel go elsewhere to constitute the secondary infestation, and the larvae which hatch after the tassel loses its attractiveness must become established elsewhere as a primary infestation.

The three curves representing the infestation in the ears are almost coincident, indicating that the infestation there is practically the same 30 days after the infestation as it was 10 days after infestation. If the primary ear infestation was augmented by the secondary infestation from the tassel migrants, an increase in the level of population would be evident in the later dissections. Indeed, if anything, there is a drop in the population. If this drop has any significance, it is probably associated with an emigration which seems to take place when the corn matures, and which cannot be explained.

The stalk infestation, on the other hand, does show an increase in the general level of population with each dissection group, which can certainly be attributed to a secondary infestation.

It is well recognized that larvae primarily attacking the tassel migrate to other parts of the plant. Since the borers and plant are growing concurrently, the migration could be the result of the borers reaching a particular stage of development requiring a change in habitat, rather than to the fact that the tassel itself reaches a condition no longer favorable to the borer. To determine this point, corn in four stages of development were made available for the first generation of the borer during 1941. Corn borer eggs gathered on June 2, and representing the first of the season, were distributed to these plants. Since the plants were infested with eggs of the same relative age, it was supposed that if growth of the larvae was responsible for the migration, the movement would occur when the borers reached a definite size regardless of the stage of the plant. It became obvious, however, that this was not the case. Instead, the migration occurred at a relatively definite stage of plant growth, namely, late tassel to early silk stages, when the tassels open out to expose the anthers. The tassels in plants of earlier stages may harbor larvae as large as the fourth instar, but in plants beyond this stage, tassels support few if any larvae of any instar. This is in line with other evidence indicating that this stage in the development of corn marks the point beyond which the primary infestation is largely in the ears rather than in the tassel.

Conclusions

1. Many earlier workers have demonstrated that certain habits and population trends of the European corn borer are associated with the growth of the host plant.

2. A classification of the growth stages of corn, prepared by Batchelder (unpublished manuscript), has proved useful in this study.

3. During the oviposition period of the corn borer moth, few eggs are deposited on plants smaller than the mid-whorl stage.

4. Even if eggs are deposited on plants smaller than the late whorl stage, few of the emerging larvae become established and survive. Beyond this stage, a gradient of survival increasing in the older plant stages appears.

5. Because of the escape from oviposition and the inability to support the larvae, plants smaller than the late whorl stage at the time of moth flight are not likely to be severely infested.

6. In plants larger than the mid-whorl stage and smaller than the early silking stage, the principal primary infestation is in the tassel.

7. In plants larger than the early silking stage, the tassel does not support larvae, and the borers which were resident there secondarily infest other parts of the plant.

8. The stalk absorbs the principal part of the secondary infestation.

9. In plants of the early silking stage and larger, the developing ears are the location preferred by the borers. Thus the borer attack in the ears is due more to a primary infestation than to the migrants from the previously infested tassel.

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PART II. STUDIES OF INSECTICIDES

NEELY TURNER

Investigations of the biology of the European corn borer made soon after its discovery in this country produced facts of use in considering insecticidal control. Worthley and Caffrey (10) stated that many of the young larvae feed on the surface of leaf blades and upon exposed portions of husks and silks. They reported the results of seven years of experiments using various insecticides, and concluded "the application of insecticides has proved ineffective in protecting growing corn or other plants from injury by the European corn borer in all experiments conducted up to the present time (1925), although it has been possible to destroy large numbers of the larvae in their early stages." The materials tested were (a) lead arsenate, calcium arsenate, magnesium arsenate, sodium fluosilicate and calcium fluosilicate in sprays and dusts, and (b) free nicotine dusts, nicotine sulfate sprays, mineral oil sprays with and without arsenicals, nitrobenzol dusts and calcium cyanide dusts. The number of treatments varied from one to nine. At times certain treatments showed promise, but sooner or later each of them failed to provide control. Calcium cyanide, sodium fluosilicate and mineral oil injured corn plants.

Simanton, Dicke and Bottger (8) tested a series of materials as dusts and as sprays. Lead arsenate and calcium arsenate failed to kill a high proportion of the larvae when used in three spray applications or four dust treatments. Barium fluosilicate and sodium fluosilicate were highly effective but injured corn plants. Calcium fluosilicate was the most satisfactory material of this type. Nicotine sulfate in sprays and dusts was not effective. Pyrethrum in dusts and sprays was effective. Talc in sprays and dusts gave inconsistent results. The applications were timed as follows: (a) Ovicides and larvicides were applied at the date of maximum oviposition, again at the beginning of hatching and finally at the maximum of hatching; (b) larvicides were applied just before and just after the maximum hatch and again four days later.

Batchelder and Questel (2) reviewed the problems of corn borer control. They stressed the fact that all first instar larvae, most second instar and many third instar larvae could be reached by insecticides. Effective treatment is difficult because the season of most rapid growth of corn coincides with the period of initial infestation by newly hatched larvae. Lead arsenate was tested with materials supposed to increase tenacity. Of these, petroleum oil emulsions were more effective than casein or fish oil soap. Oil emulsions alone were effective in killing the egg-masses which were covered by the sprays. Combinations of lead arsenate and mineral oil emulsions applied from two to four times resulted in a relatively high mortality of larvae, probably due to the good penetration of interfoliar spaces. Free nicotine and pyrethrum-soap sprays were erratic in performance.

Ficht (7) found that mineral oil emulsion-lead arsenate combinations were much more effective than lead arsenate alone. Barium and sodium fluosilicates were effective but injured the plants. Calcium fluosilicate was equally effective but not so injurious to the corn. Mechanical barriers of hydrated lime or talc were not effective. Pyrethrum and derris added to oil emulsions increased the effectiveness slightly. Nicotine sulfate was erratic in performance, and a combination of free nicotine and tannic acid appeared to be better than nicotine sulfate with or without an oxidized oil.

Batchelder, Questel and Turner (3) reported that pure ground derris root, phenothiazine and nicotine tannate were effective as sprays. The schedule of application, which had been developed by Batchelder and Questel, was four applications at intervals of five days, starting as soon as the first eggs hatched. The materials were applied to the whorls, emerging tassels and developing ears. A dual-fixed nicotine dust made by combining dry, powdered nicotine bentonite and nicotine tannate was also effective. Other forms of fixed nicotine used in dusts and dusts containing rotenone in pure ground derris or cubé root were less toxic than dual-fixed nicotine dust.

On the other hand, Baker and Questel (1) reported that dusts containing ground derris root were more effective than dual-fixed nicotine. Sprays containing pure ground derris root were outstanding in effectiveness. Various fluorine compounds were effective but injured the plants to some extent.

Problems Under Investigation

The experiments included in this report were conducted during the years 1936 to 1941, inclusive. The primary objective was the application of materials found promising by Batchelder, Questel and Turner (3) in order to determine their value under commercial conditions. Tests of other materials of special interest were made as required. The problem of a schedule of treatments was highly important, especially since any reduction in number of treatments would reduce the cost materially. Methods of application under commercial conditions were studied. One minor point of interest was the need for a spreading agent to be used with pure ground derris or cubé root in sprays.

At the outset special emphasis was placed on the development of dual-fixed nicotine dust. This material was promising in previous tests, and there was a demand for a dust for use by growers. Although some suitable sprayers were available, few growers were interested in spraying as a method of control. Moreover, the general principles developed by investigating dusts should be valid for sprays as well.

Methods

The methods used were those developed by Batchelder and Questel and described by Batchelder, Questel and Turner (3). Briefly

stated, either latin square or plots replicated in blocks were treated four times at intervals of five days in first-generation tests. The corn was planted in rows, with the plants one foot apart, rather than in hills. Knapsack, bellows-type hand dusters and three-gallon compressed-air sprayers were used in most tests. Applications were started soon after the first eggs hatched and were made to the whorls until the tassel opened, after which time the ear shoots or ears were treated. In second-generation tests the standard schedule was five applications at intervals of five days. In actual practice these schedules covered most of the oviposition period of the corn borer. Hatching rate and dates of insecticide application for two seasons have been illustrated by Batchelder, Questel and Turner (3).

For first-generation tests, early varieties of corn were planted as early as possible in the spring. Such plants were usually in the early whorl stage and from 10 to 15 inches tall when the first eggs were deposited. For second-generation tests, either an early variety was planted about July 15, or a late variety late in June. Due to variations in seasonal history of the borer and to unequal growth of the corn from season to season, the plants were from early whorl to early green tassel when infested, and from 12 to 30 inches high. In all cases reported, however, the maturity of the corn was such that the ears were infested by borers.

Results were taken at harvest time for the sweet corn. The samples were 10 or 20 stalks taken at random from the two rows in the middle of the plot, starting five plants from the end of the plot. The plants were dissected and records made of the number of borers in the stalk and in each ear. Ears were also scored as to size (marketable or cull) and infestation (borer-free or infested). The results have been reported in number of borers in 100 plants, from which the percentage reduction in borers was calculated. This was done by comparing the number surviving in treated and untreated plots. It was possible to calculate the percentage reduction of borers in ears only, but this figure was not as consistent as the one based on the entire plant. The other figure reported is the percentage of Number 1 ears borer-free. This was obtained by examining the ears before dissection for external evidence of infestation. The ears were snapped off the stalk, and feeding marks of the larvae in the husk or tip of the ear indicated infested ears. Larval feeding marks in the shank, which on removal allowed at least half the husk to remain, were not considered as cause for classification as infested. Naturally, some ears which had no borers or borer damage to kernels were included as infested because of feeding marks on the husk.

Relation Between Stalk and Ear Infestation

Considerable information has been obtained regarding the number of corn borer larvae in stalks and in ears. Table 3 summarizes this information for both generations of larvae. It will be noted that the percentage of borers in ears and percentage of infested ears do not follow any consistent pattern in relation to total number of

TABLE 3. RELATION BETWEEN STALK AND EAR INFESTATION

Year	No. borers 100 plants	% borers in ears	% ears infested
	First Generation		
1941 F	313	30.0	64.3
1940 F	336	25.2	66.1
1940 S	374	22.6	72.5
1940 M	449	26.2	76.1
1938	457	18.9	48.3
1941 M	670	29.4	62.5
1939	1,033	25.5	86.8
	Second Generation		
1936	254	27.7	15.3
1940	828	28.2	62.4
1939	932	38.4	63.8
1937	1,472	29.4	96.8
1938	1,831	38.6	79.8

larvae. There is a tendency for larger infestations to produce a greater percentage of infested ears, but discrepancies occur frequently. The data for individual plants were summarized and are shown graphically in Figures 6, 7 and 8. The average number of borers in ears of plants having from none to 22 larvae per stalk was plotted. In addition, the two generations were plotted separately, and it was noted that the ear infestation in the second generation was more severe than in the first. Figure 7 shows the results for the first generation in two successive years. In 1941 the corn was harvested July 9-12 and the ear infestation was much more severe in proportion to stalk infestation than in 1940, when the corn matured July 24-28.

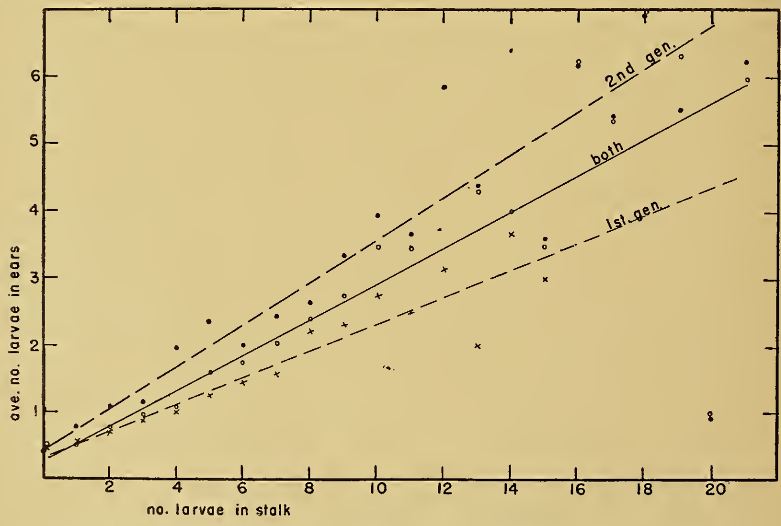

FIGURE 6. Relation between stalk and ear infestation, experiments from 1936 to 1941 inclusive.

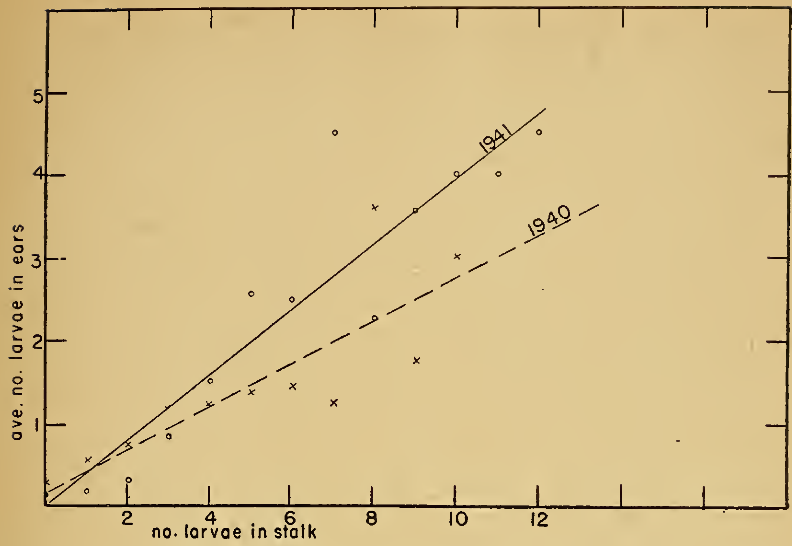

FIGURE 7. Relation between stalk and ear infestation, first generation; 1941 corn picked July 9-12; 1940, July 24-28.

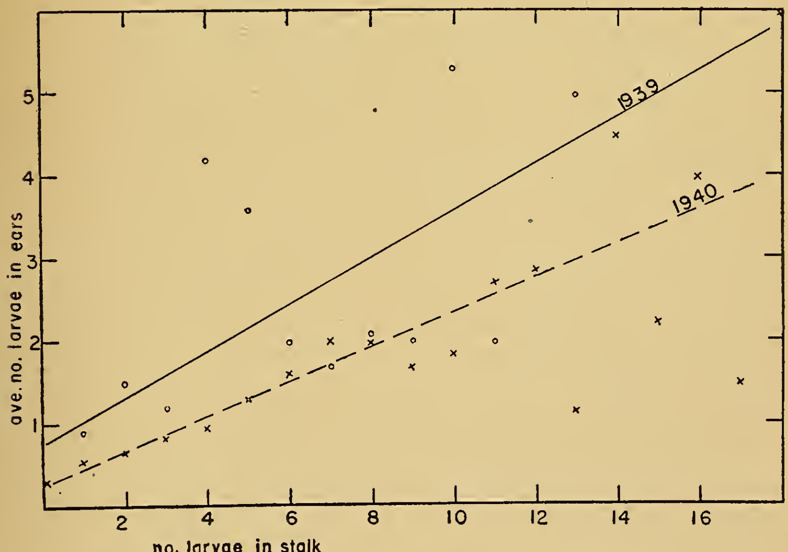

FIGURE 8. Relation between stalk and ear infestation, second generation; 1939 corn picked Sept. 6-11; 1940, Sept. 23-26.

Figure 8 shows that early harvest in the second generation (September 6-11 in 1939) was also accompanied by a relatively more severe ear infestation than late harvest in 1940 (September 23-26).

Beard (4) has shown that the tassel is the most attractive part of the corn plant to hatching larvae until ear shoots form. These data show that earlier corn, which develops ear shoots earlier in relation to the hatching of the corn borer, receives a relatively larger ear infestation than later corn. The total number of larvae in the plant may indicate the level of infestation, but cannot show the susceptibility of ears to infestation.

It is for this reason that reduction of borers in the entire plant has been used as the criterion of effectiveness in the basic insecticide studies reported later, rather than the population in ears or percentage of ears borer-free. The figures for Number 1 ears borer-free have been used in evaluating the treatments for commercial use, because that is the only result of interest to the farmer. In Table 4 these results are reported as percentage of borer-free Number 1 ears of the total yield, including small true ears. In all other tables this percentage refers only to ears of market size and is reported as percentage of Number 1 ears borer-free.

Statistical analysis of the results presented has been made by using suitable transformations. The distribution of larvae is neither normal nor Poisson. The logarithmic transformation seemed to stabilize the variance satisfactorily. However, the differences in number of larvae per plant were enormous. For instance, the number per plant in the second generation of 1938 varied from 2 to 49, with an average of 18.4. As a result differences required for statistical significance were relatively large. In all cases, except as noted, the analysis was made of the surviving population and not the percentage reduction. In spite of the fact that five or more replicates were used in each single experiment, few statistically significant differences appeared, especially in tests of schedules.

Relation of Level of Population to Control

In the course of these investigations it was noticed that there were fluctuations in the degree of control resulting from application of a standard material. Dimond, Horsfall, Heuberger and Stoddard (6) have proposed a theory, supported by some evidence, that spore load (population of spores) did not affect the slope of dosage-response curves of fungicides, but that increased spore loads displaced the curve to the right. In other words, as the number of spores increased, the degree of control with a fixed dosage of fungicide would decrease. This same theory should apply to insects as well. A series of tests using dual-fixed nicotine dust (4 percent nicotine) applied four times at intervals of five days to control first-generation corn borers yielded the following results:

Year	No. larvae 100 untreated plants	% reduction in treated plants
1941	313	77.6
1940	336	70.7
1940	411	76.1
1938	457	71.7
1941	670	68.4
1939	1,033	62.4

These figures are plotted on the log-probit scale in Figure 9. It is evident that there was a decrease in effectiveness as the number of larvae increased. Unfortunately not enough data are available to es-

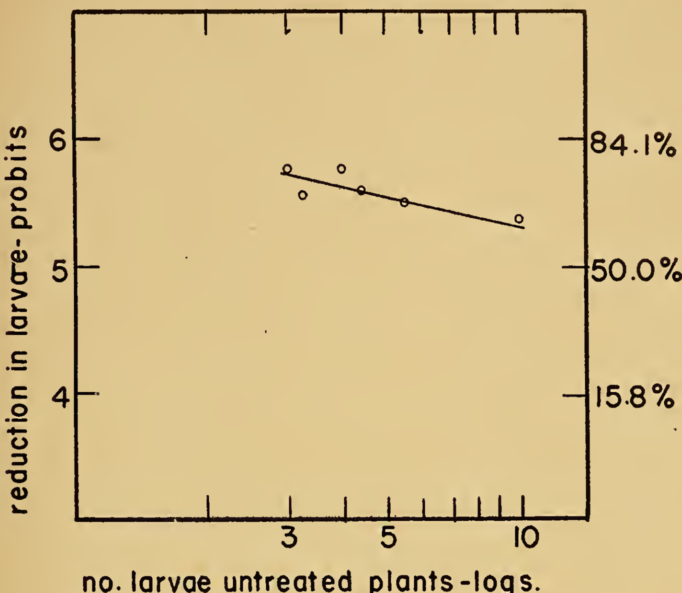

Figure 9. Relation between degree of infestation as measured by larvae in untreated plants and percentage reduction in larvae following standard treatment.

tablish an exact numerical relationship. However, this interpretation seems to account for the exceptionally low degree of control in the 1939 tests.

Sprays

Use of Spreaders With Ground Derris and Cubé Root

Batchelder and Questel (2) found that a spreading agent was necessary with arsenate of lead to aid in penetration of interfoliar spaces in which the corn borer fed.

Tests in 1936 and 1937 included comparisons of derris and cubé with and without spreading agents. The spreading agents used were sodium butylhydroxyphenylbenzenesulfonate (*Areskap*) (Baker and Questel, 1), sodium oleyl sulfate with a resinous adhesive (*Grasselli Spreader-Sticker*) and a sodium salt of water-soluble sulfonic acids made by acid treatment of petroleum (*Ultrawet*) (Walker, 9). A summary of the results of these tests is given in Table 4. With the exception of the second-generation test in 1936 with *Areskap*, the number of replicates in each test was too small to yield statistically significant differences. Moreover, there is no consistent trend with any spreader, and reversals in order of effectiveness occur. No definite advantage is shown for addition of spreading agents to ground derris or cubé root for corn borer sprays.

TABLE 4. EFFECT OF SPREADERS ON GROUND DERRIS OR CUBÉ ROOT IN SPRAYS

Year	Insecticide	Spreader	Dilution in 25 gals.	No. borers in 100 plants	% reduction of borers	% borer-free No. 1 ears
1936 I[1]	Cubé	None	1 lb.	175	72.9	63.5
	Cubé	*Areskap*	1½ oz.	117	81.4	65.4
	None	——	——	647	—	42.0
1936 II[2]	Derris	None	1 lb.	80	67.4	74.7
	Derris	*Spreader-Sticker*	1½ oz.	57	76.9	67.4
	None	——	——	245	—	64.5
	Derris	None	1 lb.	73	71.4	67.3
	Derris	*Areskap*	1½ oz.	106	58.2	65.7
	None	——	——	254	—	69.9
1937 I	Cubé	None	1 lb.	105	77.9	65.4
	Cubé	*Areskap*	1½ oz.	118	74.9	60.0
	Cubé	*Ultrawet*	1½ oz.	120	74.5	72.1
	None	——	——	470	—	36.5
1937 II	Cubé	None	1 lb.	220	85.0	57.3
	Cubé	*Ultrawet*	1½ oz.	150	89.8	64.8
	None	——	——	1,472	—	3.2

[1] First generation.
[2] Second generation.

Dusts

Materials

Batchelder, Questel and Turner (3) found that dual-fixed nicotine dust was more effective than dust containing rotenone. Baker and Questel (1) reported dusts containing rotenone to be superior to dual-fixed nicotine. In order to settle this point, at least for Connecticut conditions, three series of tests were made comparing the two materials. In all these tests the dual-fixed nicotine was the commercial preparation containing 4 percent nicotine. The derris dust contained 1 percent rotenone and the diluent was Bancroft clay. The results of the tests are given in summary in Table 5. In two of the three series dual-fixed nicotine dust was significantly more effective than derris dust. In the third test the difference was in favor of dual-fixed nicotine. The factorial experiment in 1940, involving application of both materials by hand and by machine and to wet and dry foliage, failed to show that any of these factors affected derris dust any differently than dual-fixed nicotine dust.

In one series of tests, derris dust containing 1 percent rotenone was compared with proprietary dusts containing rotenone and pyrethrum. These were (a) a dust made from total extract of derris added to a carrier (*Agicide*), containing .15 percent rotenone and (b) a similar type of pyrethrum dust (*Dry Pyrocide*) containing .2 percent pyrethrins. The results are given in Table 6 and show that the impregnated dusts, as used, were less effective than the derris dust, but not significantly so by statistical analysis.

TABLE 5. COMPARISON OF DUAL-FIXED NICOTINE DUST (4% NICOTINE) AND DERRIS DUST (1% ROTENONE)

Year	Material	Method of application	No. borers in 100 plants	% reduction in borers	% No. 1 ears borer-free
1940 I	Derris	Hand	155	62.2	65.8
	Dual-fixed nicotine	"	98	76.1	52.2
	None		411	—	30.8
1940 I[1]	Derris	Hand on dry foliage	176	47.6	69.1
	"	" " wet "	167	50.3	56.9
	"	Machine on dry foliage	184	45.1	52.6
	"	" " wet "	221	34.2	50.9
	Dual-fixed nicotine	Hand on dry foliage	98	70.7	64.1
	" " "	" " wet "	141	58.0	69.7
	" " "	Machine on dry foliage	134	60.0	56.5
	" " "	" " wet "	173	48.4	52.7
	None		336	—	33.9
1940 II[2]	Derris	Hand	337	59.3	63.2
	Dual-fixed nicotine	"	217	73.7	72.5
	None		828	—	36.2

[1] Analyzed factorially—differences between derris and dual-fixed nicotine significant.
[2] Difference required for significance—75.

TABLE 6. COMPARISON OF IMPREGNATED DUSTS WITH DERRIS DUST

Year	Material	% active ingredient	No. borers in 100 plants	% reduction in borers	% No. 1 ears borer-free
1940 II[1]	Derris dust	1 rotenone	337	59.3	63.2
	Agicide dust	.15 rotenone	428	48.2	49.4
	Pyrocide dust	.2 pyrethrins	404	51.2	52.4
	None		828	—	36.2

[1] Analyzed factorially—differences between three materials not significant.

Commercial nicotine bentonite dust and dual-fixed nicotine dust have been compared in 1938 and 1941. The nicotine bentonite preparation requires a less expensive manufacturing process and therefore merited interest. The results are given in Table 7, and dosage-re-

TABLE 7. COMPARISON OF NICOTINE BENTONITE AND DUAL-FIXED NICOTINE DUSTS

Year	Material	% nicotine	No. borers in 100 plants[1]	% reduction in borers	% No. 1 ears borer-free
1938 I	Nicotine bentonite	3.0	192	58.0	71.8
	Dual-fixed nicotine	4.0	132	71.7	80.3
	None	—	457	—	51.7
1941 I	Nicotine bentonite	2.0	168	46.9	57.5
	" "	3.0	147	53.0	55.4
	" "	4.0	123	60.7	58.1
	Dual-fixed nicotine	2.0	191	38.9	59.9
	" " "	3.0	110	64.9	70.8
	" " "	4.0	70	77.6	79.8
	None	—	313	—	35.7

[1] Difference required for significance—28.

sponse curves for the 1941 experiment in Figure 10. These curves are plotted using the percentage reduction of larvae in probits and logarithm of dosage (Bliss, 5). This transformation was designed

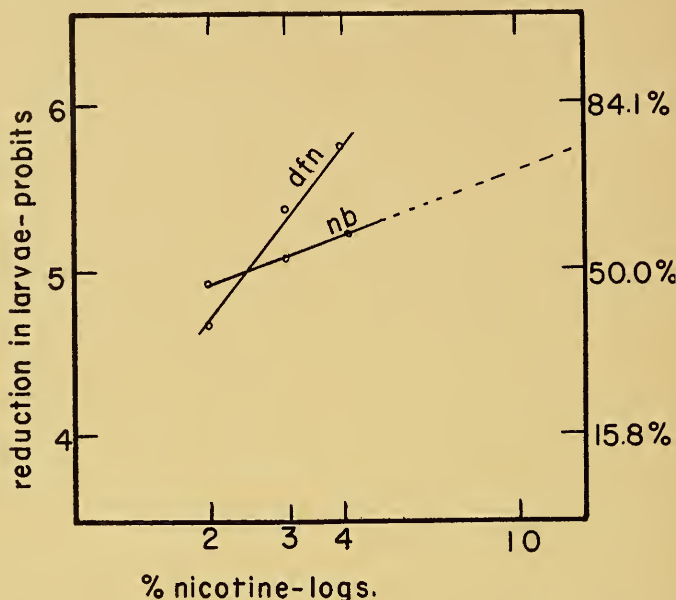

FIGURE 10. Dosage-response curves for dual-fixed nicotine and nicotine bentonite dusts.

for use in laboratory studies of the effect of dosage on mortality. Its application to field tests has been discussed by Dimond, Horsfall, Heuberger and Stoddard (6). Nicotine bentonite was more effective at 2 percent nicotine content than dual-fixed nicotine dust, but much less effective at 4 percent nicotine content. Analysis of variance using probits for percentage reduction of larvae in each plot showed that curvature was negligible and that the two curves were not parallel. By calculation the amount of nicotine in nicotine bentonite necessary to kill the same percentage of larvae as 4 percent dual-fixed nicotine was determined as 11.06 percent nicotine with a possible variation of from 5.75 to 24.1 percent. The precision of the extrapolation is not very great, because the dosages did not cover a wide range. Dual-fixed nicotine at 4 percent nicotine content does not kill the high percentage of larvae desired. Since nicotine bentonite is definitely less toxic than dual-fixed nicotine, no greater precision is needed to eliminate nicotine bentonite in its present form.

Methods of Application

Field plot treatment during these experiments was made with hand dusters for convenience. As soon as the system of dusting corn was established as effective in a series of experiments, it was necessary

to test power dusters. Hand applications were directed to the parts of the plant needing treatment, and the plants were dusted individually. Power dusters, on the other hand, must be adjusted to deliver the dust to the row of corn, and plants cannot receive individual attention.

Three series of tests were made comparing hand and power dusters (Tables 5 and 8). In 1939 a power duster, with four nozzles, was

Table 8. Hand and Machine Application of Dual-Fixed Nicotine Dust

Year	Method	No. borers in 100 plants	% reduction in borers	% No. 1 ears borer-free
1939 II	Hand	387	58.5	57.5
	None	932	—	—
	Machine	482	48.9	44.9
	None	944	—	—
1940 II	Hand - dry foliage	217	73.7	74.4
	Machine-" "	175	78.8	78.4
	Hand - wet foliage	217	73.7	74.9
	Machine-" "	105	87.3	84.0
	None	828	—	37.6

used to dust two rows. This was a wheelbarrow-type machine not self-propelled. Two nozzles were directed on each row. When the whorl was treated both nozzles were directed downwards. Later treatments to ears were made with a nozzle on each side of the row, directed down and back to cover the ears. The difference in results was in favor of hand treatment but was not significant statistically. In 1940 a two-row self-propelled power duster was used. This machine had two nozzles used for each of the two rows, adjusted as described above. The first test in 1940 (see Table 5) was the factorial design and showed that hand application was significantly better than machine. In the second test in 1940 the machine treatment was more effective than hand, but not significantly so. It is probable that the improved effectiveness of machine treatment was due to more experienced operation and adjustment of nozzles. It would be difficult to adjust any machine to dust each plant as effectively as can be done with a hand duster. However, if the machine treatment is approximately as effective as hand treatment it is of value commercially.

Application to wet and dry foliage. One large-scale test made in 1939 using hand dusters was less effective than the plot treatments with the same duster and operator. One difference in conditions was striking: the large-scale test was made to corn growing in a river valley. The dust was applied at dawn and the plants were very wet. The plot tests were made on a field located on a hill. The dusts were applied at 8 o'clock in the morning and the plants were dry or nearly so. In 1940 two series of tests were made using dusts on wet

and dry plants. In the wet series dusts were applied at daylight and in the dry series at dusk. Dew was not always present, especially in the second-generation test. The results have been given in Tables 5 and 8. In the first-generation test, treatment on dry foliage was superior but not quite significant statistically. In the second generation, treatment to wet plants was more effective and the difference was barely statistically significant. In this latter case the difference was in the treatment made by machine on wet foliage and suggests an interaction between the use of the machine and wet foliage. Such an interaction did not occur in the first-generation test.

The application of dust to dry foliage is probably at least as effective as to wet foliage. In order to kill the borers the dust must settle into the whorl, ear shoots and axils of the leaves. It cannot be blown in by a blast of air from the nozzles. Wet foliage might conceivably prevent effective settling into the plant, because the dust would tend to adhere rather than to roll or slide into the proper places.

Schedules of Treatment

As stated above, the standard schedule has been four treatments at intervals of five days for the first generation and five treatments at the same interval for the second generation. In effect these schedules provided for treatment during a major part of the time eggs were hatching. In addition, the repeated treatments were necessary to cover newly-produced leaves, as noted by Batchelder and Questel (2). The effectiveness of the standard schedule was established in 1937. The question then arose as to whether or not it was the most effective schedule for general use. The cost of the treatment was relatively high, limiting application to high-priced, extra early corn. One possibility of reducing the cost was reduction in number of treatments. This involved a study of the effect of timing treatments on control as well as the effect of number of applications. This study began in 1938 and is still in progress. This report of progress has been arranged according to the ideas developed rather than chronologically.

It is a well-known fact that if one application of an insecticide results in 50 percent mortality, two applications do not necessarily cause 100 percent mortality. If the second were as effective as the first, the maximum mortality would be 75 percent of the original number of insects. In other words, the effect of the two treatments is more nearly geometric than arithmetic. If timing of treatments had no effect on mortality, it should be possible to draw a curve showing the relationship between number of treatments and control. If, on the other hand, timing was important, those treatments or schedules timed properly should be more effective than expected, and those timed improperly should be less effective than expected.

The data available have been examined on the basis of these assumptions. In 1941 an experiment was designed to determine the effectiveness of each single treatment of the standard four-treatment schedule. The standard schedule was four treatments at intervals of

five days—June 16, 21, 26 and July 1. Three or four days after each treatment 10 plants were taken at random from each of the five plots which had been randomized in blocks. These were dissected and a record made of the number of larvae, their size (instar) and their position in the plant. A similar sample was taken from untreated plants. Single treatments were applied on June 21, 26 and July 1, with a dissection three days after treatment, five days later, and at harvest time. Dual-fixed nicotine dust (4 percent nicotine) was used in all plots and applied by means of a bellows-type hand duster. Plants were dusted individually, the June 16 and 21 dusts being applied to whorls and developing tassels, and the June 26 and July 1 dusts to ear shoots.

At the time treatment was started, many plants had developed as far as the late whorl stage and a few were in the early green tassel stage. In order to obtain some information on mid-whorl application, which is normally about the time of the first treatment, plants in this stage were selected in the plots. Tags were placed on those which bore eggs, and the samples dissected on June 19 were taken from these tagged plants. Later dissections were from plants taken at random.

The schedules of treatments and dissections were as follows:

Treatment	Dissections
Standard—June 16, 21, 26, July 1	June 19, 25, 30, July 4 and July 9-12
June 21	June 25 and 30, July 9-12
June 26	June 30, July 4 and July 9-12
July 1	July 4 and July 9-12
None	June 19, 25, 30, July 4 and July 9-12

A summary of the results of the dissections is given in Table 9, calculated as percentage reduction in borers by comparison with bor-

Table 9. Effect of Individual Treatments

Date treated	Date dissected	Total No. borers	% reduction in borers	% No. 1 ears borer-free
June 16	June 19	68	58.0	
None	" "	162		
June 16 & 21	June 25	91	72.8	
" 21	" "	152	57.5	
None	" "	334		
June 16, 21, 26	June 30	130	55.9	
" 21	" "	212	27.6	
" 26	" "	226	22.9	
None	" "	293		
June 16, 21, 26, July 1	July 4	124	69.3	
" 26	" "	243	39.8	
July 1	" "	238	41.1	
None	" "	404		
June 16, 21, 26, July 1	July 9-12	106	68.4	74.0
" 21	" "	223	33.4	40.0
" 26	" "	248	25.9	28.0
July 1	" "	203	39.4	30.0
None	" "	335		37.5

ers in untreated plants, and is shown graphically as number of borers in Figure 11. One point is notable: the number of larvae in untreated plants dissected on June 30 is unexpectedly small. This results in a smaller percentage reduction in borers for treated plants dissected at the same time.

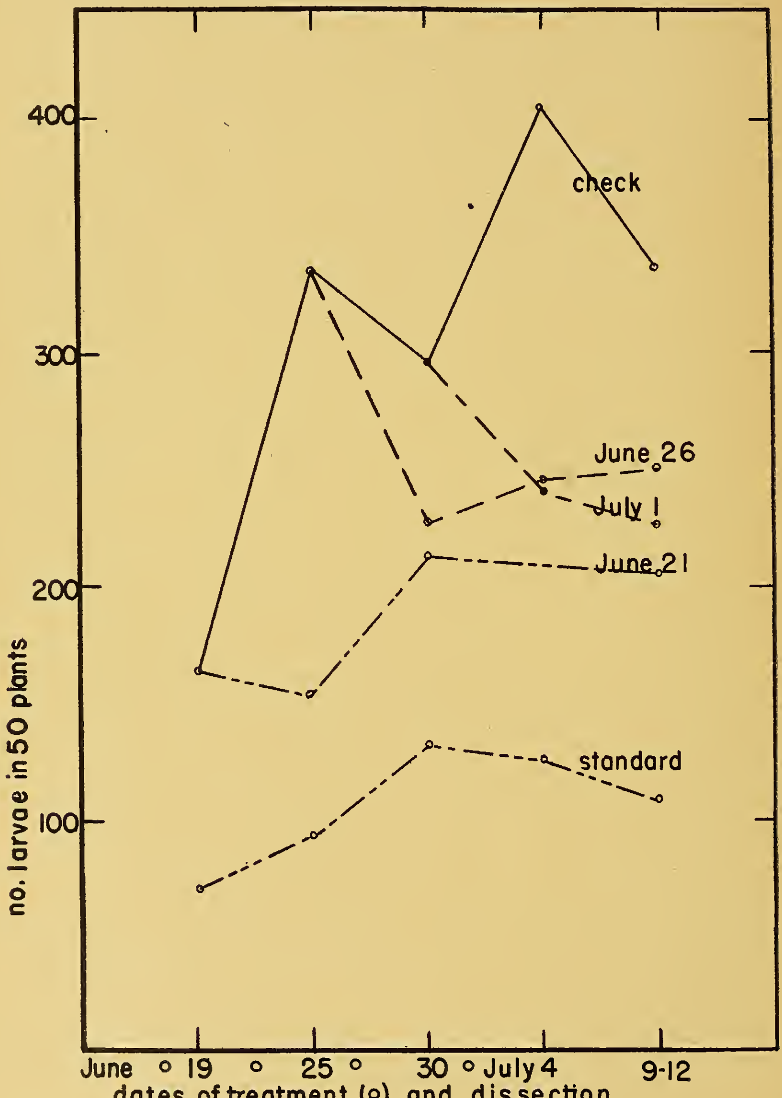

FIGURE 11. Effect of single treatments and the standard schedule of four treatments on the number of larvae in the entire plant. Solid line course of infestation in untreated plants. Effects of single applications started from curve of untreated plants.

Analysis of variance has shown that no single application was more effective than any other single treatment. There is also no evidence of any substantial residual effect of treatment extending beyond four days after treatment.

Since in this one test there appeared to be no definite timing effect of this standard schedule, data available on comparisons of number of treatments have been studied. These data have been plotted with number of treatments on the logarithmic scale and percentage reduc-

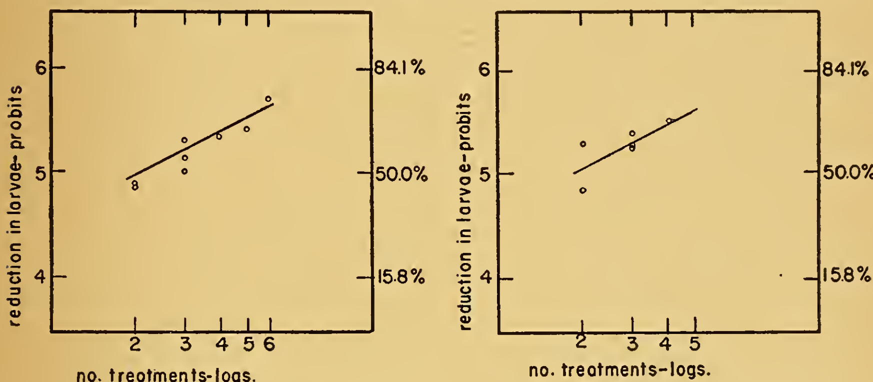

FIGURE 12. Left, relation between number and timing of treatments, first generation, 1939. Right, relation between number and timing of treatments, first generation, 1938.

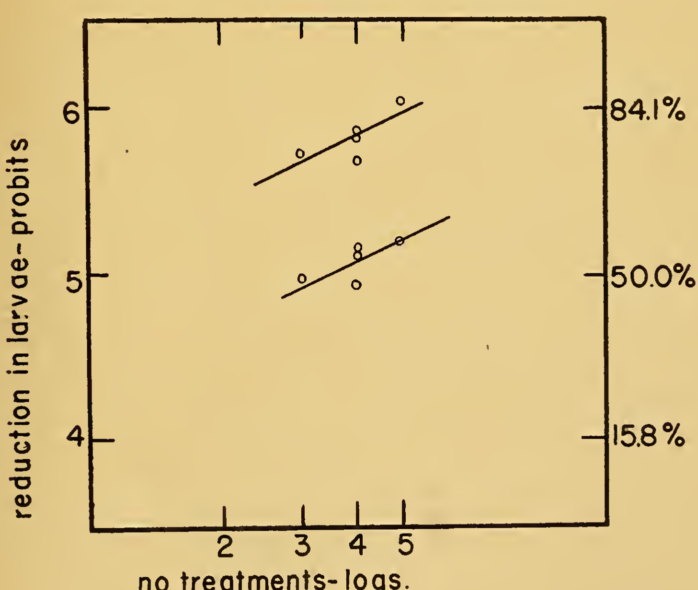

FIGURE 13. Relation between number and timing of treatments, second generation; 1938 above, 1939 below.

tion of larvae on the probit scale. There is evidence that this correction is not perfect, but until a more exact method is available it may be used.

In these tests no applications were made before the first hatching of larvae, and all treatments had been completed before hatching for the generation ceased. Any schedule which was better than expected should appear above the curves (in Figures 12 and 13), and any less effective than the average below the curves.

In the first generation of 1939 a test was made using dual-fixed nicotine dust in a series of two to six applications. The series from three to six covered approximately the same period of time and were spaced from three to seven days apart. The results are given in Table 10, and the curve plotted in Figure 12. On the basis of the assumptions made, the four and five-treatment schedules were somewhat

Table 10. Number of Applications (1939 I)

Schedules (all dates June)	No. borers in 100 plants[1]	% reduction in borers	% No. 1 ears borer-free
7, 10, 13, 16, 19, 22	255	75.3	52.1
7, 11, 15, 19, 23	355	65.7	50.0
7, 12, 17, 22 (standard)	387	62.4	50.0
7, 13, 19, 25	388	62.4	47.8
7, 14, 21	398	61.5	47.8
9, 14, 19	525	49.2	31.0
12, 17, 22	468	54.7	35.4
12, 19	580	43.9	32.4
7, 14	566	45.2	25.7
None	1033		

[1] Difference required for significance—75.

less effective than expected, and the three-treatment schedule at seven-day intervals slightly more effective. Three treatments at five-day intervals starting June 9 were definitely less effective than the other three-treatment schedules. The first possible explanation would be the action of rain. The records show that the only rain of more than .08 inch was recorded on June 14 and was 1.10 inches. The June 14 treatments were made after the rain, and the June 13 applications were repeated on June 14. This left only the standard or 7, 12, 17, 22 schedule that could have been seriously affected by the rain. This schedule was not substantially less effective than expected.

In general, the results indicate that number of applications in these tests was of more importance than timing (all applications made during hatching period). In three cases—two, three and four treatments—two different timings could be compared. The two and four-treatment schedules were remarkably alike in each case; but the three treatments at intervals of seven days were more effective than either of the other three-treatment schedules.

A series of empirical tests of schedules for the first generation of the European corn borer is given in Table 11. These were really tests both of the number of treatments and their timing. The results of the 1938 tests were plotted in Figure 12. There are some deviations from the schedules applied at regular intervals starting as soon as the first eggs hatched, but these were apparently in no regular pattern. The most radical deviation was in the two applications June 20 and 29, 1938. However, by analysis of variance these did not differ significantly from the June 15 and 22 schedule.

TABLE 11. FIRST-GENERATION SCHEDULE TESTS

Year	No. applications	Interval (days)	Dates	No. borers in 100 plants[1]	% reduction in borers	% No. 1 ears borer-free
1938	4	5	June 15, 20, 25, July 1	132	71.1	80.3
	3	5	" 17, 22, 27	183	59.5	78.6
	3	5	" 20, 25, July 1	163	64.4	74.8
	3	7	June 15, 22, 29	180	60.6	75.6
	2	7	" 15, 22	258	43.4	72.5
	2	7	" 20, 29	178	61.0	75.2
	None	—	——	457	—	51.7
1940 S[2]	4	5	June 13, 18, 25, 30	66	82.2	76.7
	3	7	" 13, 21, 30	121	67.9	64.4
	None	—	——	371	—	—
1940 M[3]	4	5	June 13, 18, 25, 30	129	71.3	66.7
	3	7	" 13, 21, 30	117	73.8	62.7
	None	—	——	449	—	37.7

[1] Difference required for significance—128.
[2] Variety Spancross.
[3] " Marcross.

The other point of interest in Tables 10 and 11 is the comparison between three applications at intervals of seven days and four at intervals of five days. In three of the four tests there was a difference, not significant, in favor of four applications. In the fourth test the reverse was true. From the curves in Figures 11 and 12, it is evident that the difference between these two would be about 7 percent if timing were not a factor. They actually differ on the average by 5.5 percent, and the precision of the tests was not great enough to measure this amount.

Second-generation schedule tests are given in Table 12 and plotted in Figure 13. In each of the years 1938 and 1939 one schedule was substantially less effective than the others, but not significantly so. The performance of four treatments at intervals of seven days was about as expected, except in the 1940 test in which it was unexpectedly high.

TABLE 12. SECOND-GENERATION SCHEDULE TESTS

Year	No. applications	Interval (days)	Dates	No. borers in 100 plants	% reduction in borers	% No. 1 ears borer-free
1938	5	5	Aug. 8, 13, 18, 23, 28	260	85.8	76.8
	4	5	" 13, 18, 23, 28	440	75.9	62.1
	4	7	Aug. 8, 15, 22, 29	346	81.1	67.0
	4	7	" 13, 20, 27, Sept. 3	359	80.4	63.4
	3	7	Aug. 8, 15, 22	407	77.8	70.0
	None			1831		20.2
1939	5	5	Aug. 7, 12, 17, 22, 27	387	58.5	57.5
	4	5	" 12, 17, 22, 27	420	54.9	40.0
	4	7	Aug. 7, 14, 21, 28	403	56.7	48.6
	4	7	" 12, 19, 26, Sept. 2	485	47.9	45.0
	3	7	Aug. 7, 14, 21	470	49.5	32.4
	None			932		16.1
1940	5	5	Aug. 12, 17, 22, 29, Sept. 1	217	73.8	74.9
	4	7	Aug. 12, 19, 26, Sept. 1	187	77.3	77.7
	None			828		37.6

Discussion of Schedule Tests

The variations in the standard schedule tested in these experiments indicate that, as far as they are concerned, the number of treatments was more important than the timing. It is evident that the approach to the problem used, that is, empirical comparisons of schedules at equal intervals, did not produce any important information. Therefore some other approach must be used and a different basis of timing attempted.

Position of the larvae and control. In the schedule experiment, carried out in 1941 and described above, the position of the larvae in treated plants was recorded. The information obtained has been summarized in Table 13 and shown graphically in Figures 11, 14, 15 and 16.

In the standard schedule, the June 16 and 21 treatments were made to the developing whorl, and the June 26 and July 1 treatments to the ear shoots or ears. Since this was a field experiment some dust undoubtedly reached other parts of the plant, such as the leaf sheath. Furthermore, reduction of borers in stalk and possibly leaf sheath might be accomplished by killing migrating larvae. Protection of ears is the primary purpose of the schedule. In 1941 the ear shoots were not treated until June 26, when a sizeable infestation was already present. Examination of Table 13 and Figure 14 shows that the June 26 treatment was not very effective in protecting the ear

TABLE 13. POSITION OF BORERS AND CONTROL
Parts of Plant Treated Marked with an Asterisk.

Treatment	Dissected	Position	No. borers	No. borers untreated plants	% reduction in borers
June 16	June 19	External	3	5	40.0
		*Whorl	10	28	64.3
		*Tassel	43	118	63.6
		Leaf sheath	4	6	33.3
		Ear shoot	8	5	+
			68	162	58.0
June 16, 21	June 25	*Tassel	49	176	72.2
		Leaf sheath	5	48	89.6
		Ear shoot	35	93	62.4
		Stalk	2	17	88.2
			91	334	72.8
June 16, 21, 26	June 30	Tassel	22	45	51.1
		*Leaf sheath	27	71	61.9
		*Ear shoot	51	89	42.7
		Stalk	30	88	65.9
			130	293	55.6
June 16, 21, 26, July 1	July 4	Tassel	12	16	25.0
		*Leaf sheath	16	67	76.1
		Ear shoot	11	65	83.1
		*Ear	19	88	78.4
		Stalk	66	168	60.7
			124	404	69.3
June 16, 21, 26, July 1	July 9-12	Tassel	0	4	100.0
		*Leaf sheath	5	24	79.2
		Ear shoot	16	45	64.4
		*Ear	13	85	84.7
		Stalk	72	177	59.3
			106	335	68.4
June 21	June 25	*Tassel	105	176	40.3
		*Leaf sheath	9	48	81.3
		Ear shoot	37	93	60.2
		Stalk	1	17	94.1
			152	334	54.4
June 21	June 30	*Tassel	29	45	35.6
		*Leaf sheath	51	71	28.2
		Ear shoot	61	89	31.4
		Stalk	71	88	19.3
			212	293	27.6

TABLE 13. POSITION OF BORERS AND CONTROL (continued)

Treatment	Dissected	Position	No. borers	No. borers untreated plants	% reduction in borers
June 21	July 9-12	*Tassel	1	4	75.0
		*Leaf sheath	18	24	25.0
		Ear shoot	35	45	22.2
		Ears	52	85	38.8
		Stalk	97	177	44.1
			203	335	39.4
June 26	June 30	Tassel	66	45	+
		*Leaf sheath	40	71	43.7
		*Ear shoot	65	89	26.9
		Stalk	55	88	37.5
			226	293	22.9
June 26	July 4	Tassel	18	16	+
		*Leaf sheath	46	67	31.3
		Ear shoot	27	65	58.4
		*Ears	44	88	50.0
		Stalk	108	168	35.7
			243	404	39.8
June 26	July 9-12	Tassel	0	4	100.0
		*Leaf sheath	10	24	58.3
		Ear shoot	38	45	15.6
		*Ears	47	85	44.7
		Stalk	154	177	12.99
			249	335	25.7
July 1	July 4	Tassel	14	16	12.5
		Leaf sheath	34	67	49.3
		Ear shoot	34	65	47.7
		*Ear	40	88	54.5
		Stalk	116	168	30.9
			238	404	41.1
July 1	July 9-12	Tassel	1	4	75.0
		Leaf sheath	8	24	66.7
		Ear shoot	26	45	42.2
		*Ear	58	85	31.8
		Stalk	131	177	25.98
			224	335	33.1

shoots in the standard schedule but was effective when applied as a single treatment. All three single applications resulted in almost identical control in the ears at the time of the last dissection.

There are two possible sources of ear infestation: (a) primary infestation from newly-hatched larvae and (b) secondary infesta-

tion by migration of partly grown larvae from other parts of the plant. Figure 14 shows that both the standard schedule and single application of June 21 reduced the ear infestation in the June 25 dissection. The treatment was made to whorls and tassels only in both cases. Some dust drifts to other parts of the plant, but it is in-

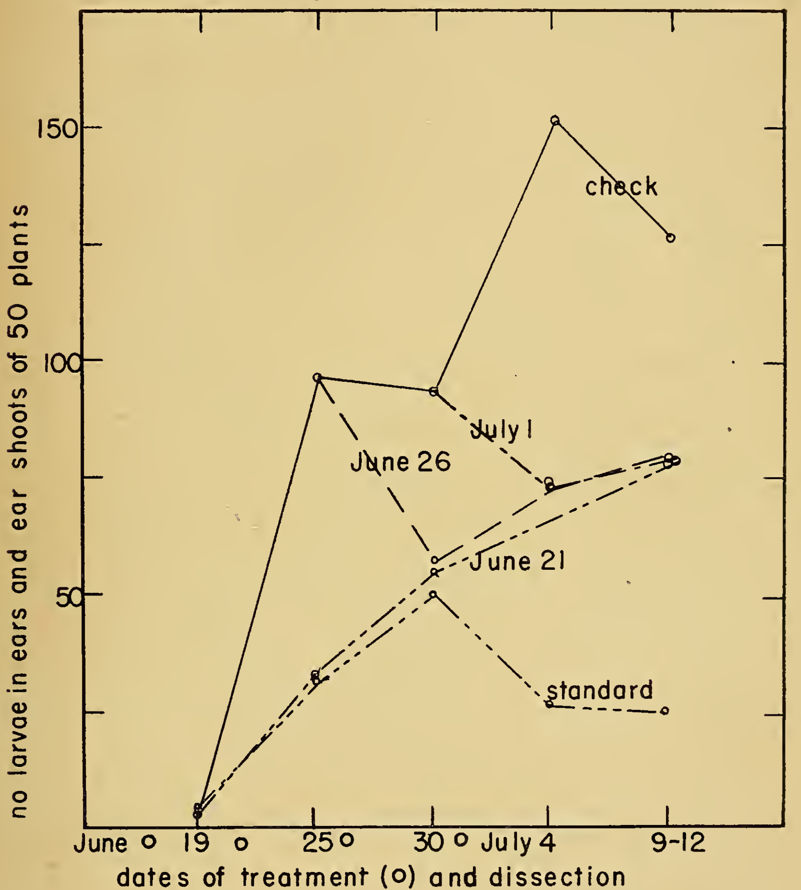

FIGURE 14. Effect of single treatments and the standard schedule of four treatments on the number of larvae in ears and ear shoots. Solid line course of infestation in untreated plants. Effects of single applications started from curve of untreated plants.

conceivable that enough dust reached the ear shoots to cause this reduction in borers. Furthermore, migration is not a likely explanation since the tassel population was at its peak on June 25 (Fig. 16). It is probable that the newly hatched larvae wandered over the plant enough to come in contact with the dust, and therefore failed to reach the ears. Incidentally, the instar data for the June 25 dissection show that there were 19 first and 16 second-instar larvae, and in the untreated, 41 first, 50 second and 2 third-instar larvae.

There is no evidence in the data at hand that any appreciable number of larvae migrating from the tassels infested the ears in this experiment. Figures 15 and 16 indicate that the stalk received these migrants. This is additional evidence to that reported by Beard (4) on the same subject.

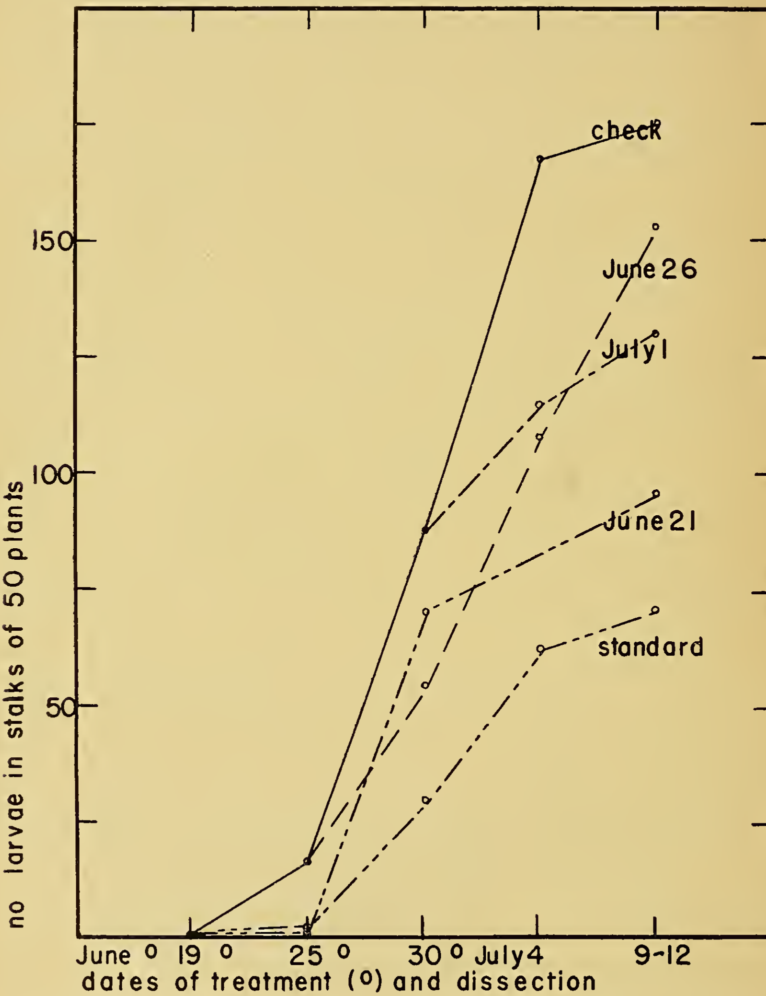

FIGURE 15. Effect of single treatments and the standard schedule of four treatments on the number of larvae in stalks.

On the whole, the data presented in Table 13 and the accompanying figures indicate that the standard schedule reduces the number of larvae in the plant by killing some of them at various points following each application. No one treatment stands out as being the most effective, and no one time as critical. This fact should explain satis-

factorily the results of tests of schedules summarized in Tables 10 to 12.

Treatment of ears only. The basis for the standard schedule of treatments is the protection of ears in two ways: (a) the lower-

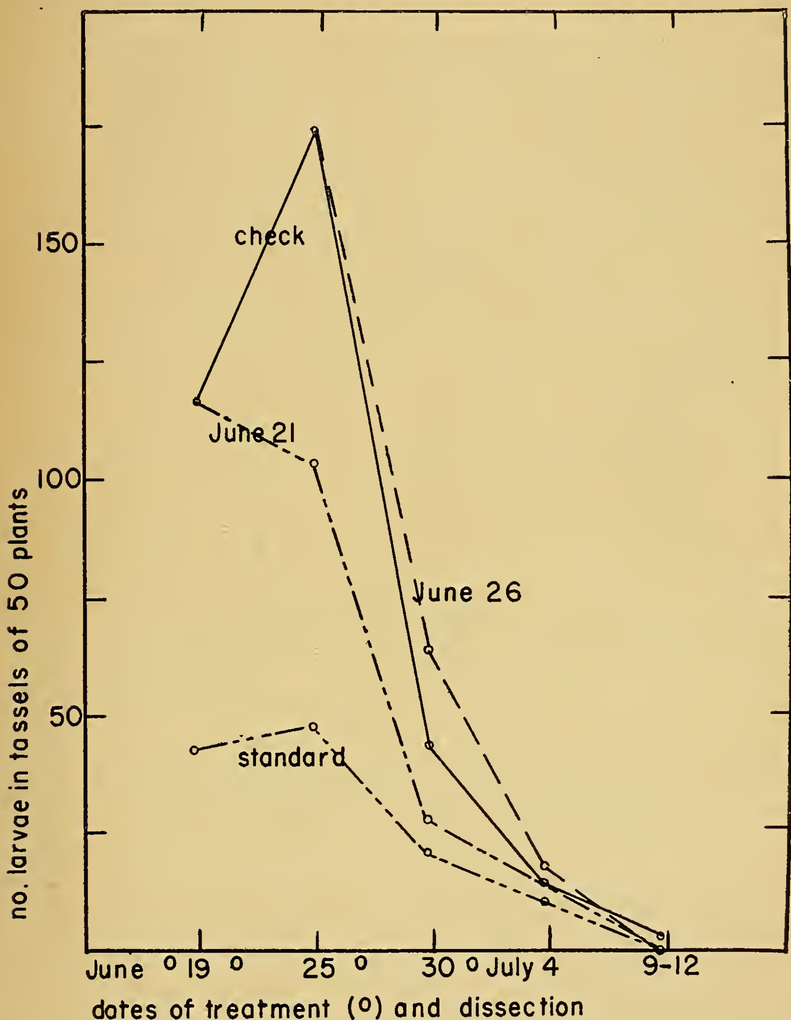

FIGURE 16. Effect of single treatments and the standard schedule of four treatments on the number of larvae in tassels.

ing of population of migrating larvae by killing the borers in the whorl and tassel, and (b) primary protection of the ears by direct treatment after the tassel opened. The question arose as to whether or not treatment of ear shoots and ears only would kill migrating larvae as well as those which entered the ears directly after hatching.

In 1940 a spray of pure ground derris root (4 percent rotenone) at the rate of 1 pound in 25 gallons of water was applied as a standard schedule on June 13, 18, 25 and 30. In comparison, three treatments were made to ear shoots and ears: (1) on June 28, as soon as the ear shoots had formed, (2) on July 8, early silk, and (3) on July 15, late silk. Dissections were made during the period July 24 to 29 when the ears were ready for harvest. In 1941 the same material was applied as an ear spray on June 24, July 1 and 5. The growth of the corn was not very uniform in the field, and the timing was not particularly good. The crop was harvested July 9-12. In addition to the ear spray, dual-fixed nicotine dust was applied on the same dates, and the standard dust schedule on June 16, 21, 26 and July 1. The results are summarized in Table 14, which shows that ear treatment was highly effective in 1940 and much less so in 1941. This

Table 14. Results of Ear Treatment

Year	Type of treatment	Schedule	No. borers in 100 ears	% reduction of borers in ears	% No. 1 ears borer-free
1940	Spray	Standard	71	62.4	61.8
	"	Ears only	106	43.9	54.1
	None	—	189	—	32.0
1941	Spray	Ears only	56	57.9	40.9
	Dust	Standard	33	75.2	67.6
	"	Ears only	65	51.1	31.9
	None	—	133	—	28.1

might be due in part to poor timing in 1941 and in part to different distribution in the latter year. The promising results of 1940 certainly indicate that more work with this type of treatment might be profitable.

Summary

The literature describing results on which these investigations were based is summarized and the methods of procedure outlined.

Comparisons of pure ground derris and cubé roots suspended in water and applied with and without spreading agents showed no consistent advantage following use of these spreading agents.

Dual-fixed nicotine dust containing 4 percent nicotine was consistently more effective in controlling the European corn borer than dusts containing 1 percent rotenone in pure ground derris root.

Dusts made by impregnating inert materials with extracts of pure ground derris root or of pyrethrum flowers were not significantly less effective than rotenone dust.

Dosage-response curves for dual-fixed nicotine dust and nicotine bentonite dusts cross over. At lower percentage nicotine, nicotine bentonite was more toxic than dual-fixed nicotine, but the reverse was true when nicotine content was increased. Approximately 11 percent

nicotine in nicotine bentonite would be required to be as effective as 4 percent nicotine in dual-fixed nicotine.

Application of dust by means of hand dusters was more effective than by means of a power duster.

Data on application of dust to wet or dry foliage were conflicting.

Various modifications of the standard schedule of four treatments at five-day intervals for control of the first generation were less effective than the standard.

Evidence is presented to show that in the tests made, where treatment was confined to the hatching period, number of treatments was more important in general than any of the timing tried.

Application of four treatments at intervals of seven days was almost as effective as five treatments at intervals of five days to control second-generation larvae.

Treatment of ears only was effective in 1940 and ineffective in 1941.

Dissection of plants following each application of the standard schedule indicated that the control obtained was accomplished by a general reduction in the population. No one treatment seemed to be more effective than any other. Ear infestation was apparently from newly hatched larvae.

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